Demonstration of the Surface Stabilized Combustor for Advanced Industrial Gas Turbines

Peer Review of the Microturbine and Industrial Gas Turbine Programs

March 12-14, 2002

Fairfax, VA

Neil K. McDougald

Project Goals

Develop a commercially viable low-emissions combustion system for industrial gas turbines.

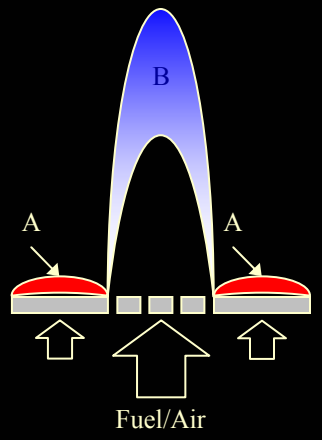
- < 3-ppm NO_X (15% O_2)
- < 10-ppm CO (15% O_2)
- < 10-ppm UHC (15% O_2)
- 90 to 100% load operating range
  - Stretch goal 60 to 100% load operation
- 4% combustor pressure drop
  - Stretch goal 3% combustor pressure drop

Approach

- Adapt successful CSB microSTAR technology to Gas Turbine service – nanoSTAR
- Enhanced lean stability
- Lower NO_X emissions than aerodynamically stabilized lean premixed injector
- Compatible with annular, can-annular and external can gas turbine combustors
- Single combustion zone
- No extraordinary control scheme

Technology

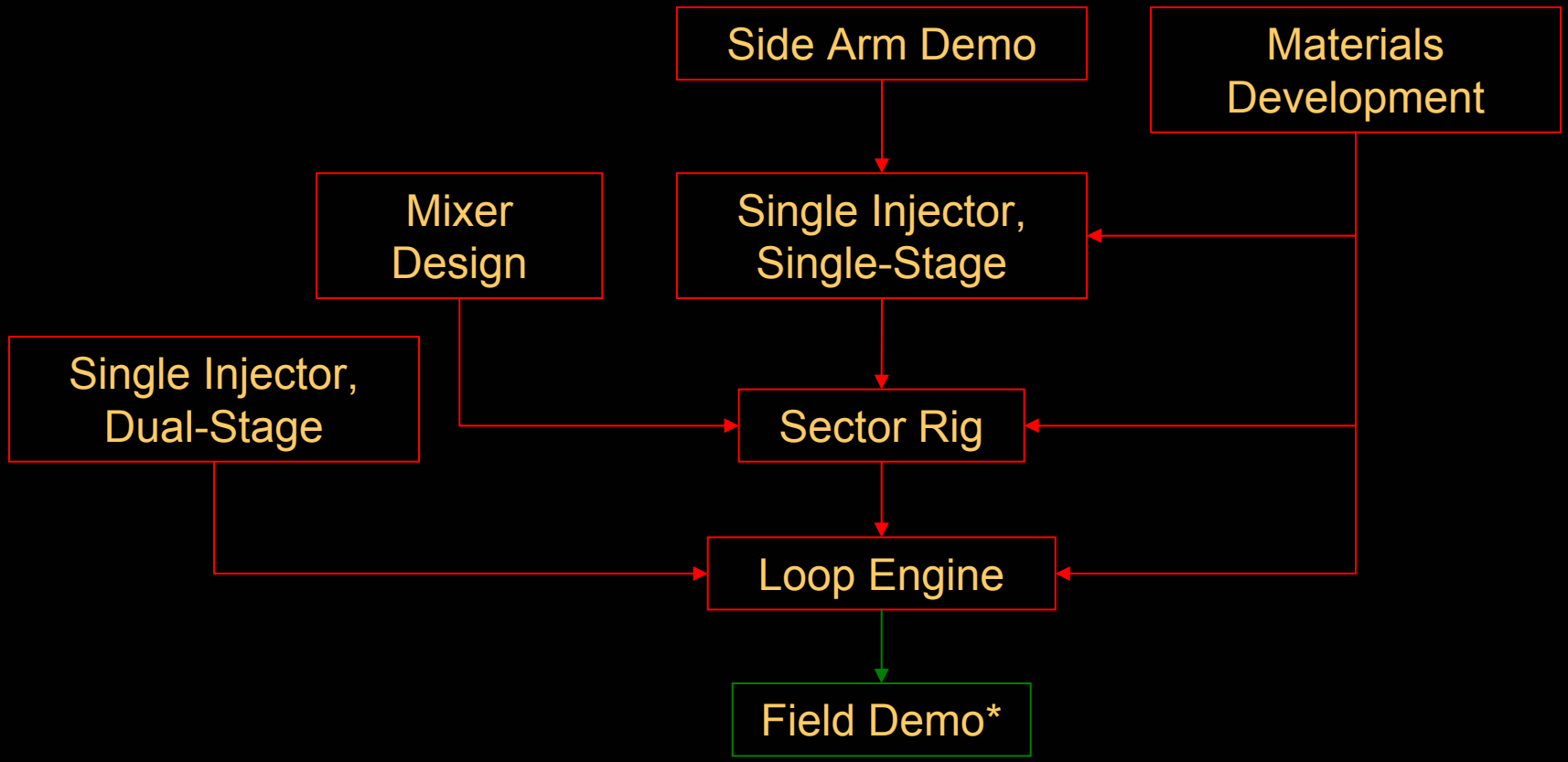
- Porous Surface is selectively perforated to achieve radiant and stabilized laminar blue flame regions
- Dry Low NO_X with high volumetric heat release
  - Surface Firing Rate up to 1,500,000 Btu/hr-ft^2-atmosphere
  - At 10:1 Pressure Ratio and 10,000 Btu/hr-kW Heat Rate Yields 1.5 Megawatts Per Square Foot of Surface



ALZETA CORPORATION

Advanced Combustion Clean Air Solutions for Industry and Our Environment

Technical Development Path



*Beyond Scope of Current Project

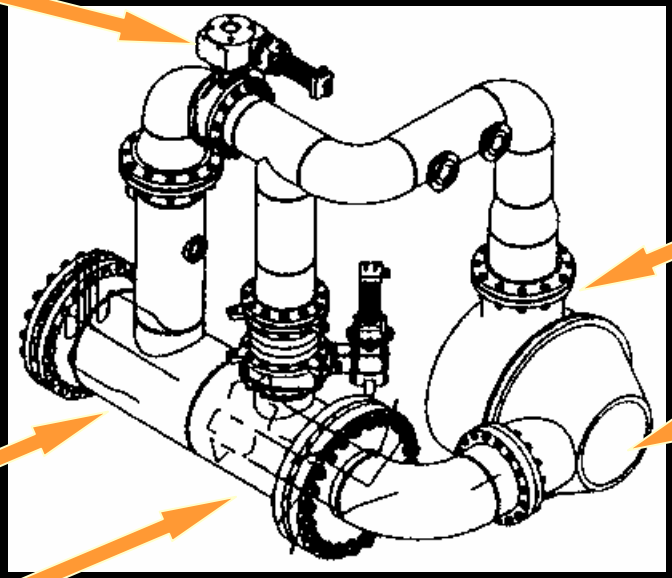
ALZETA CORPORATION

Advanced Combustion Clean Air Solutions for Industry and Our Environment

Overview

- Select Milestones
  - ✓ Saturn Demonstration – Completed 6/01
  - ✓ Cast Taurus 60 Injector – Completed 10/01
  - ✓ Correct Poor Flow Distribution – Completed 11/01
  - ✓ In-house Casting Process Development – Completed 2/02
  - ✓ Mixer Concept Screening Tests – Completed 2/02
  - ➢ Single Taurus 60 Injector Tests – In Progress, 3/02
  - – Multiple Injector, Sector Tests – 4/02
  - – Multiple Zone Injector Tests – 5/02
  - – Full Annular, Loop Rig Tests – 9/02
  - ¤ Engine Demonstration – 2003 (stretch goal)

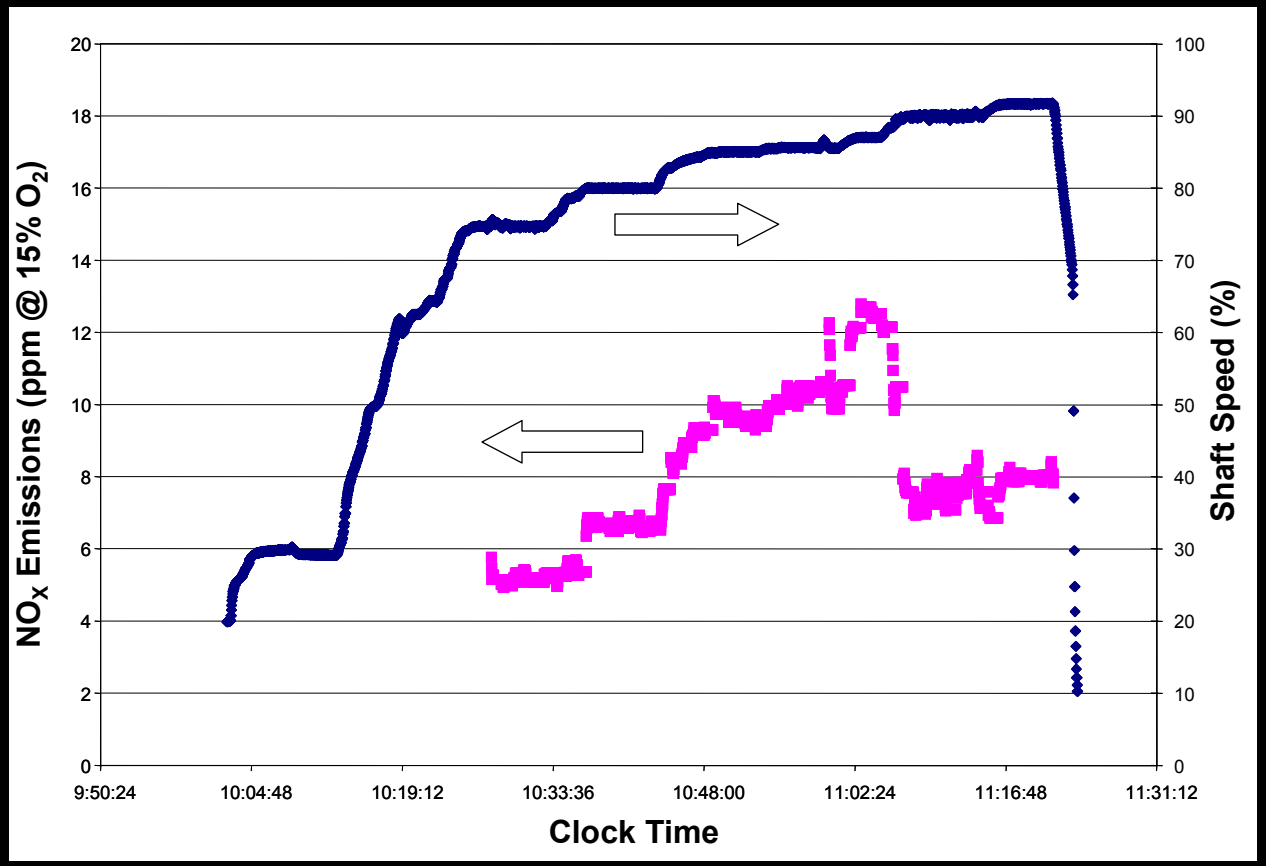
Saturn Side-Arm



ALZETA CORPORATION

Advanced Combustion Clean Air Solutions for Industry and Our Environment

Saturn Results



ALZETA CORPORATION

Advanced Combustion Clean Air Solutions for Industry and Our Environment

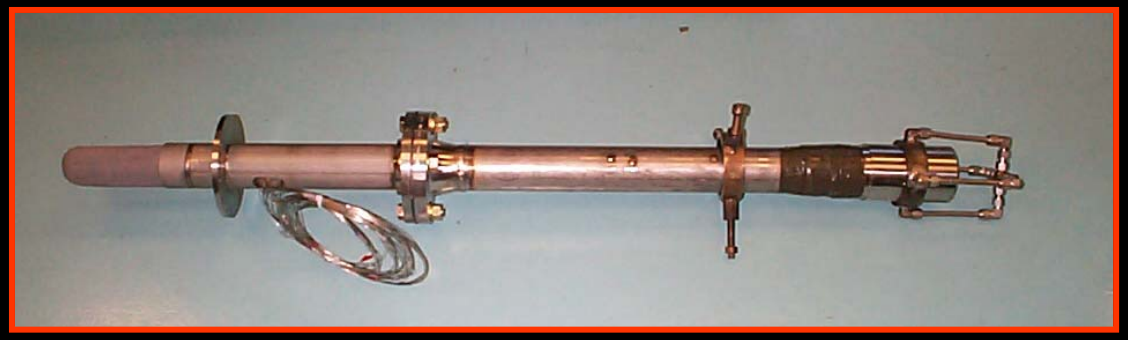
Saturn Results

- Saturn Testing
  - Day 1: Start up ramp through combustor sustained operation
  - Day 2: Start up to 92% of full load speed with manual control of air-split
  - Day 3: Automated start up ramp to 95% speed
- Observations
  - Reliable and repeatable ignition
  - Stable performance at all condition
  - Control logic consistent with other dry low NO_X systems

Engine-Ready Mixer Development

- “Perfect” premixer used in preliminary testing
- Five “engine” mixer prototypes fabricated
- Compact, modular designs that can be adapted to existing combustor
- Target spatial uniformity +/- 3% of mean fuel concentration
- Target pressure loss < 2% (mixer only)
- Down-select to 2-3 concepts and optimize

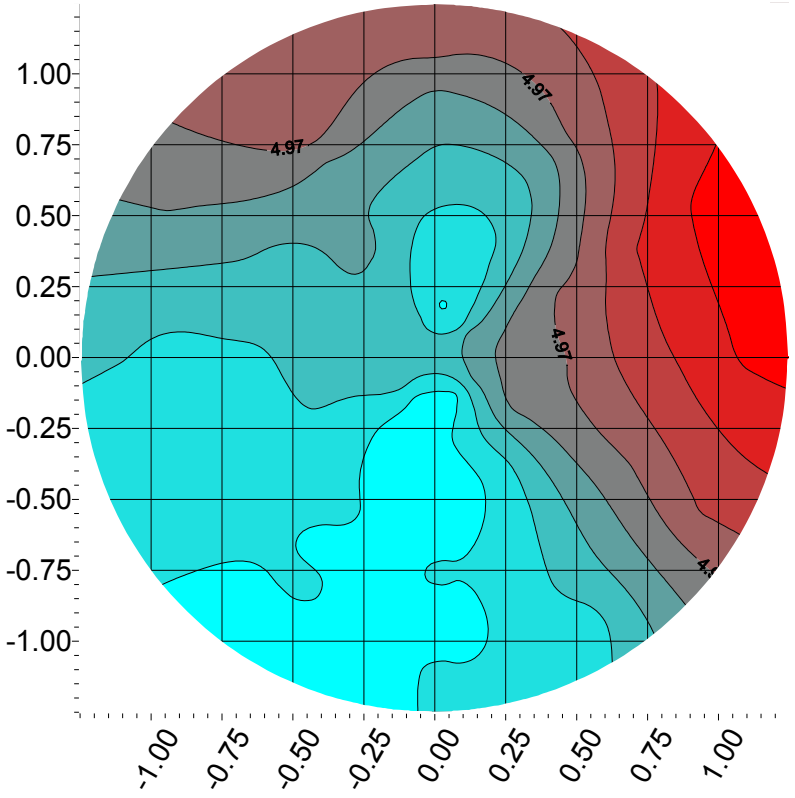
Fuel-Air Mixers

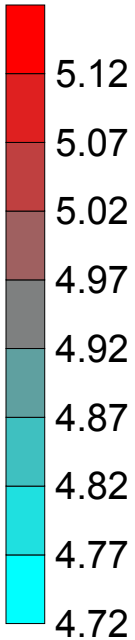


ALZETA CORPORATION

Advanced Combustion Clean Air Solutions for Industry and Our Environment

Typical Mixture Concentration Plot





Date: 8/17/01

Avg = 4.89

Min = 4.72
(-3.5%)

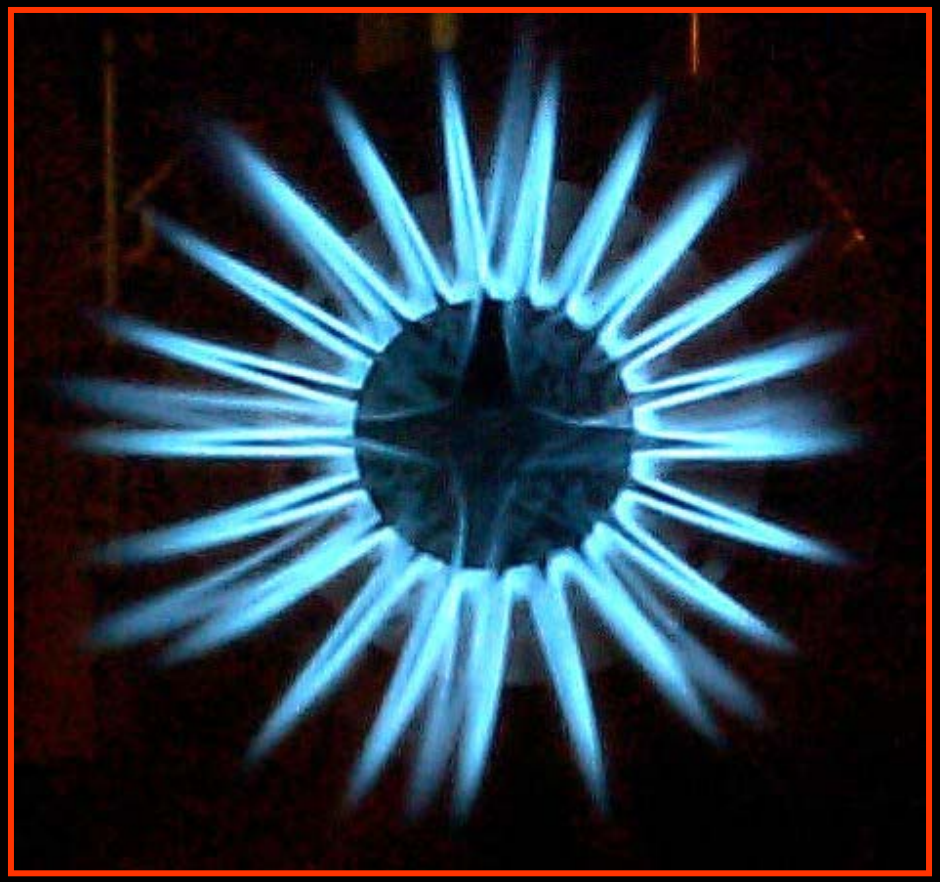
Max = 5.13
(+4.9%)

DP/P = 1.9%

ALZETA CORPORATION

Advanced Combustion Clean Air Solutions for Industry and Our Environment

Single-Stage Burners

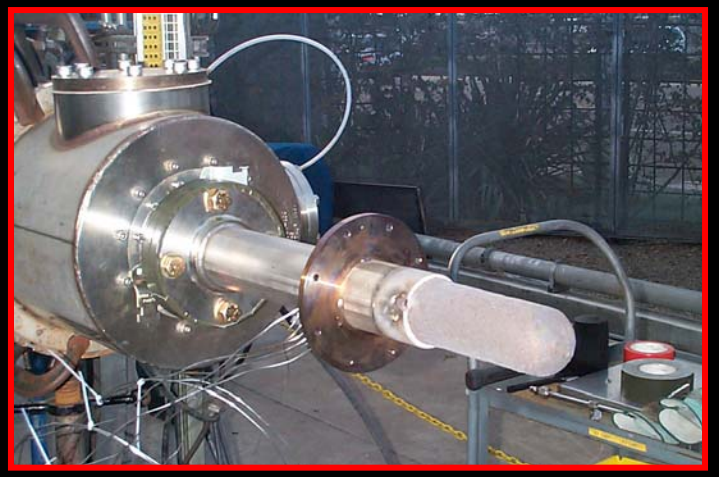


ALZETA CORPORATION

Advanced Combustion Clean Air Solutions for Industry and Our Environment

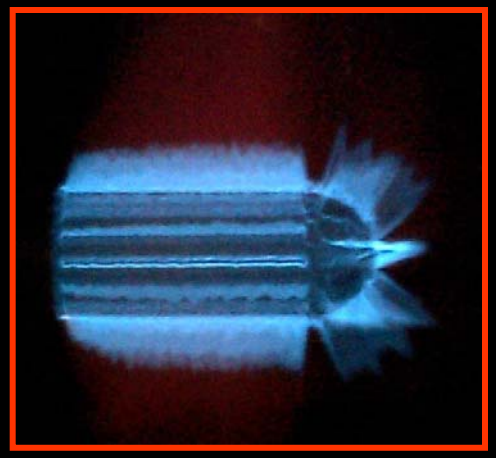
Atmospheric Burner Testing

- Conducted outdoors on Solar's Spur Rig
- Allows excellent flame visualization
- Tests generally conducted both before and after pressurized testing of burner
- Approximate lean blowout tests may be conducted

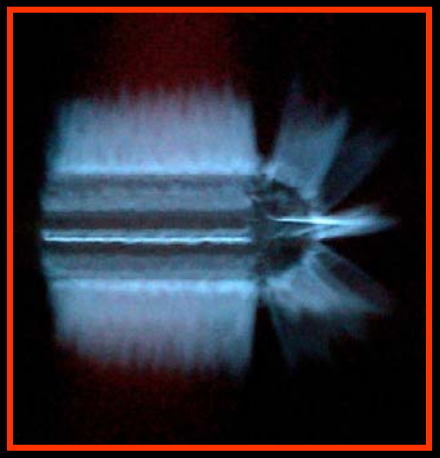


ALZETA CORPORATION

B004 Atmospheric Testing - Before



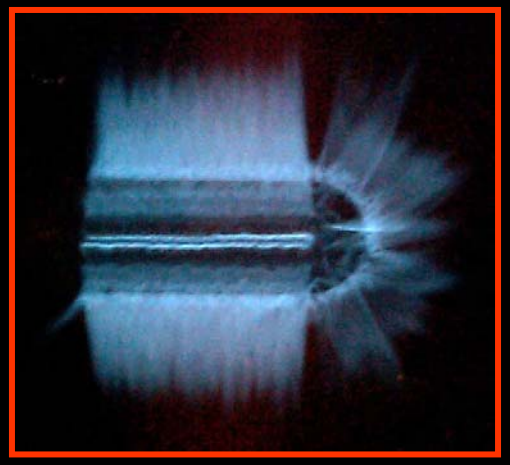
Nominal Firing Rate

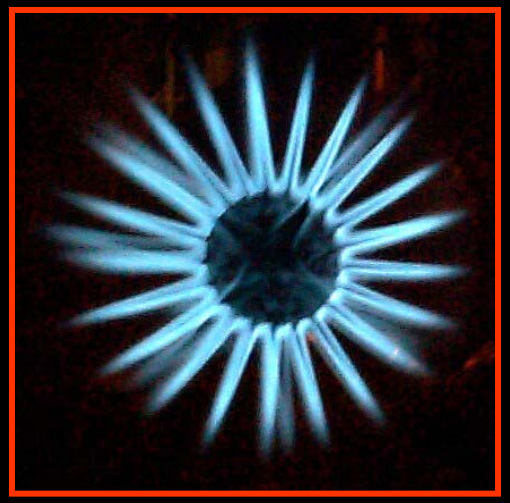


High Firing Rate

- “Narrow” stripe pattern
- Perforated cylinder insert
- Surface machined precisely to specified diameter
- Flame front highly uniform

B004 Atmospheric Testing - After



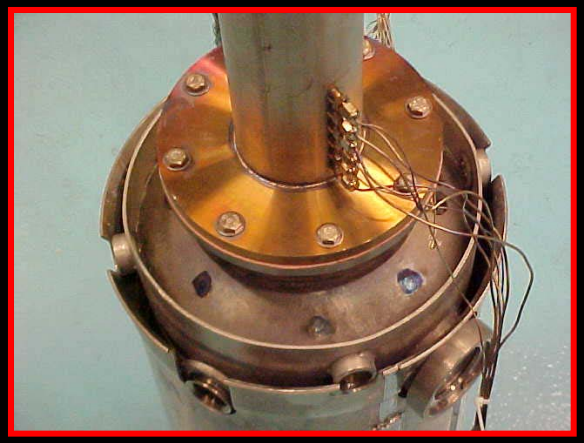


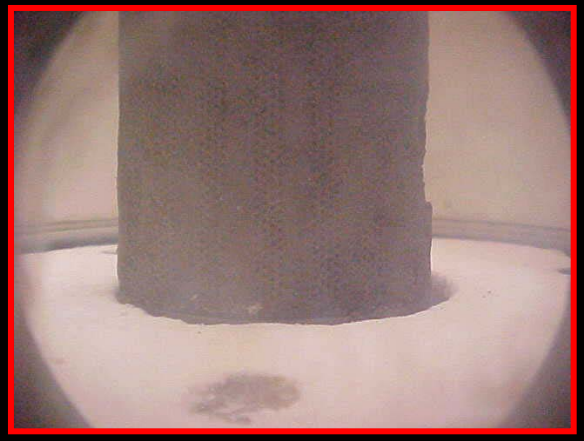
- Overheat condition resulted in small hole near mounting ring
- No significant effects of hole observed
- Surface hole largely overlaps mounting ring
- No apparent short-term effects of dome oxidation
- B004 may be used in future pressure testing

Single-Stage Burner Test Plan

- ✓ Simulated engine (T-60) operating conditions
- ✓ Performance mapping (lean blowout and blow-off) at each pressure and temperature
- Degrading mixing effects
- Pressurized ignition
- Maximum firing temperature
- Flashback assessment

Burner/Liner Assembly





ALZETA CORPORATION

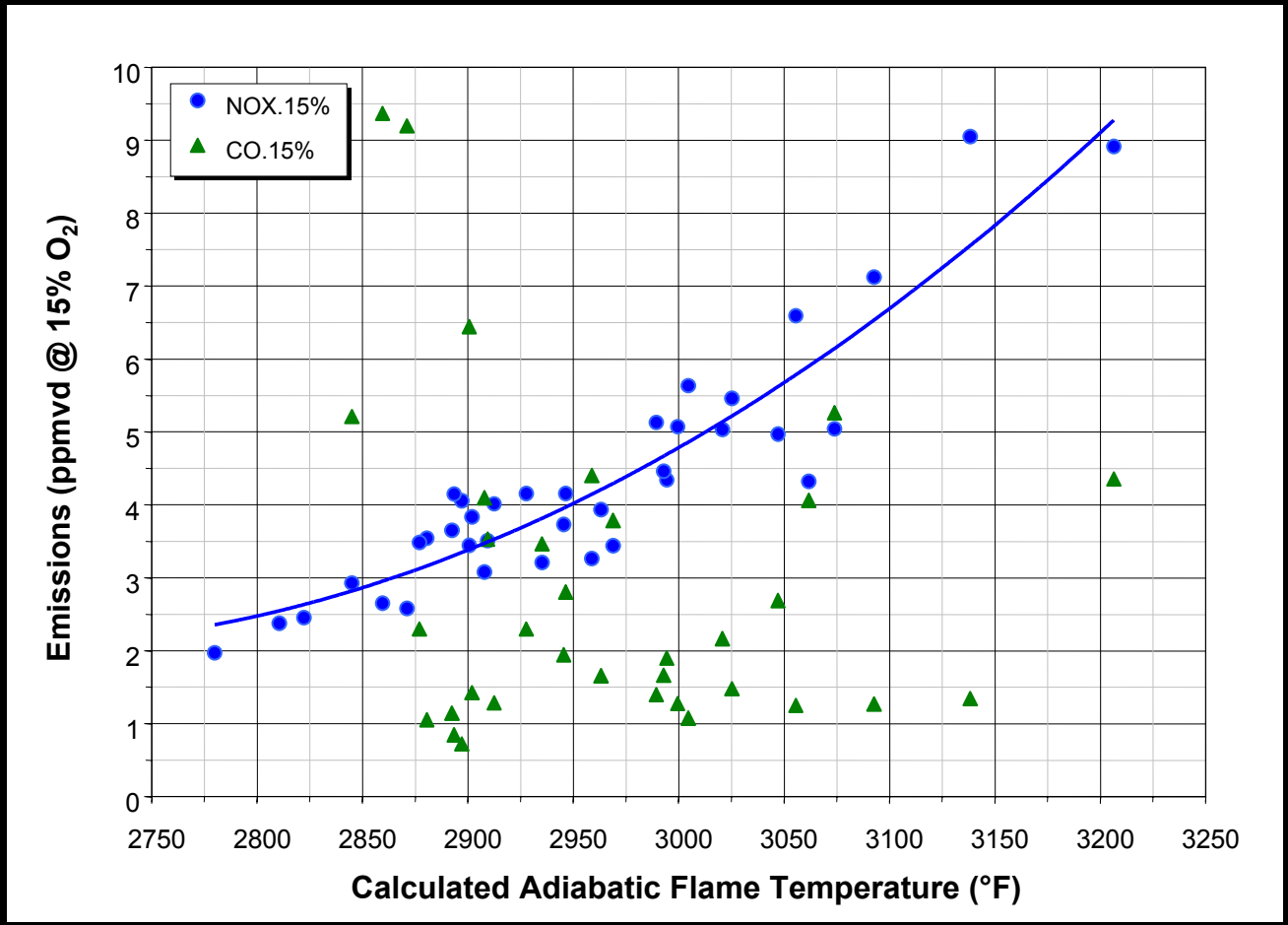
Simulated T60 Operating Conditions

- Successful demonstration of all simulated engine load conditions
- Stable operation throughout test matrix
- Low NO_X (2 ppm at 12 atmospheres)
- Low CO and HC
- NO_X and CO “cross-over” at 4 ppm

ALZETA CORPORATION

Advanced Combustion Clean Air Solutions for Industry and Our Environment

Simulated T60 Operating Conditions

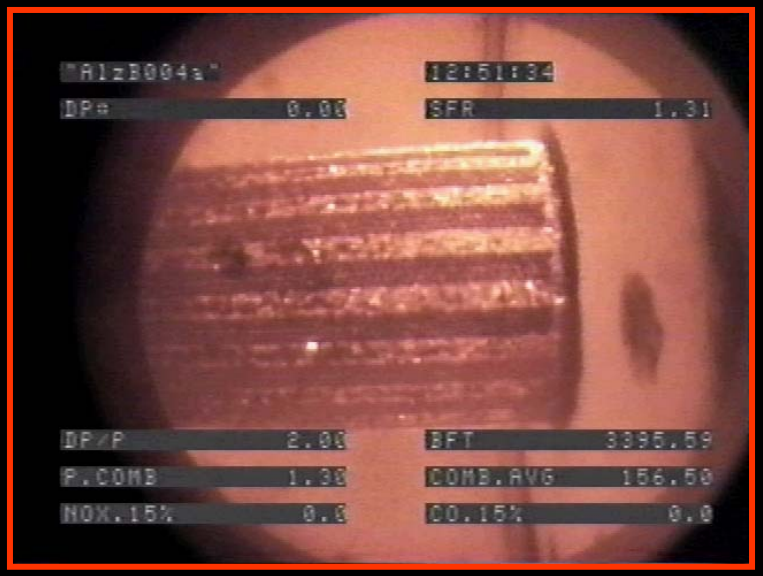


ALZETA CORPORATION

Advanced Combustion Clean Air Solutions for Industry and Our Environment

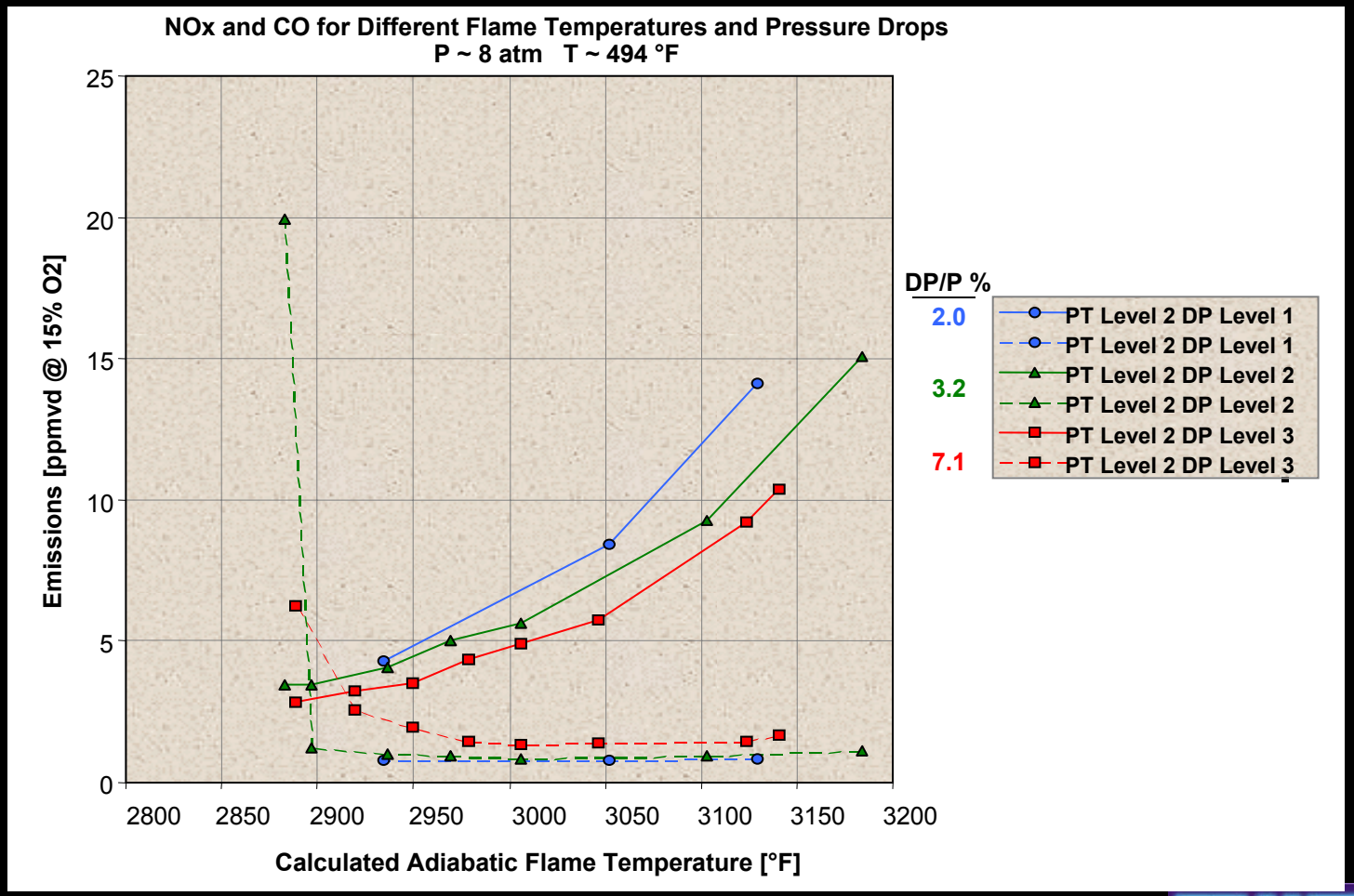
Performance Mapping

- Completion of 7 lean blowout ramps
- Slight impact of changing SFR identified
- Low NO_X (below 3 ppm when tuned)
- Low CO and HC
- Minor overheating observed



ALZETA CORPORATION

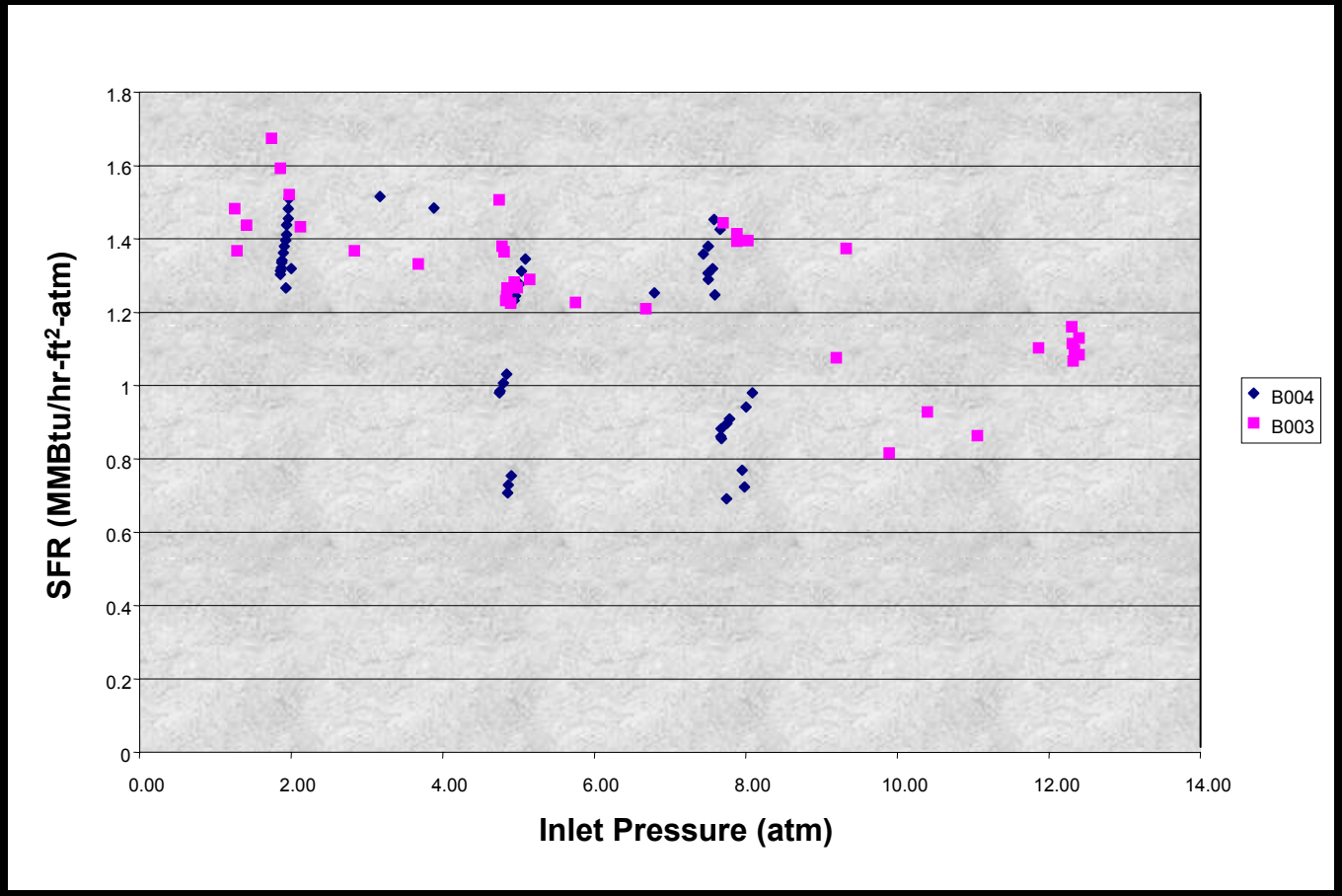
Performance Mapping Data



ALZETA CORPORATION

Advanced Combustion Clean Air Solutions for Industry and Our Environment

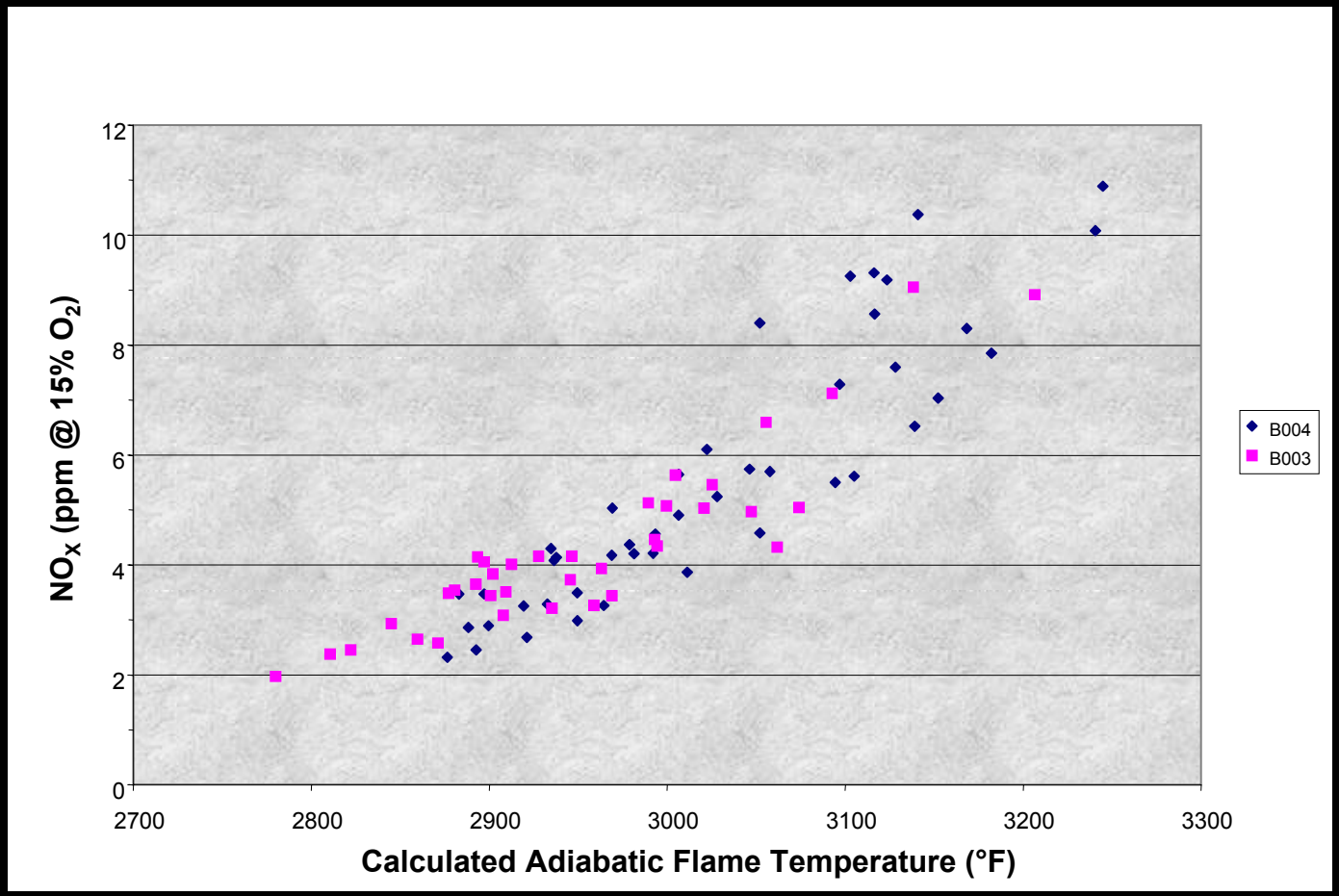
Demonstrated Operating Envelope



ALZETA CORPORATION

Advanced Combustion Clean Air Solutions for Industry and Our Environment

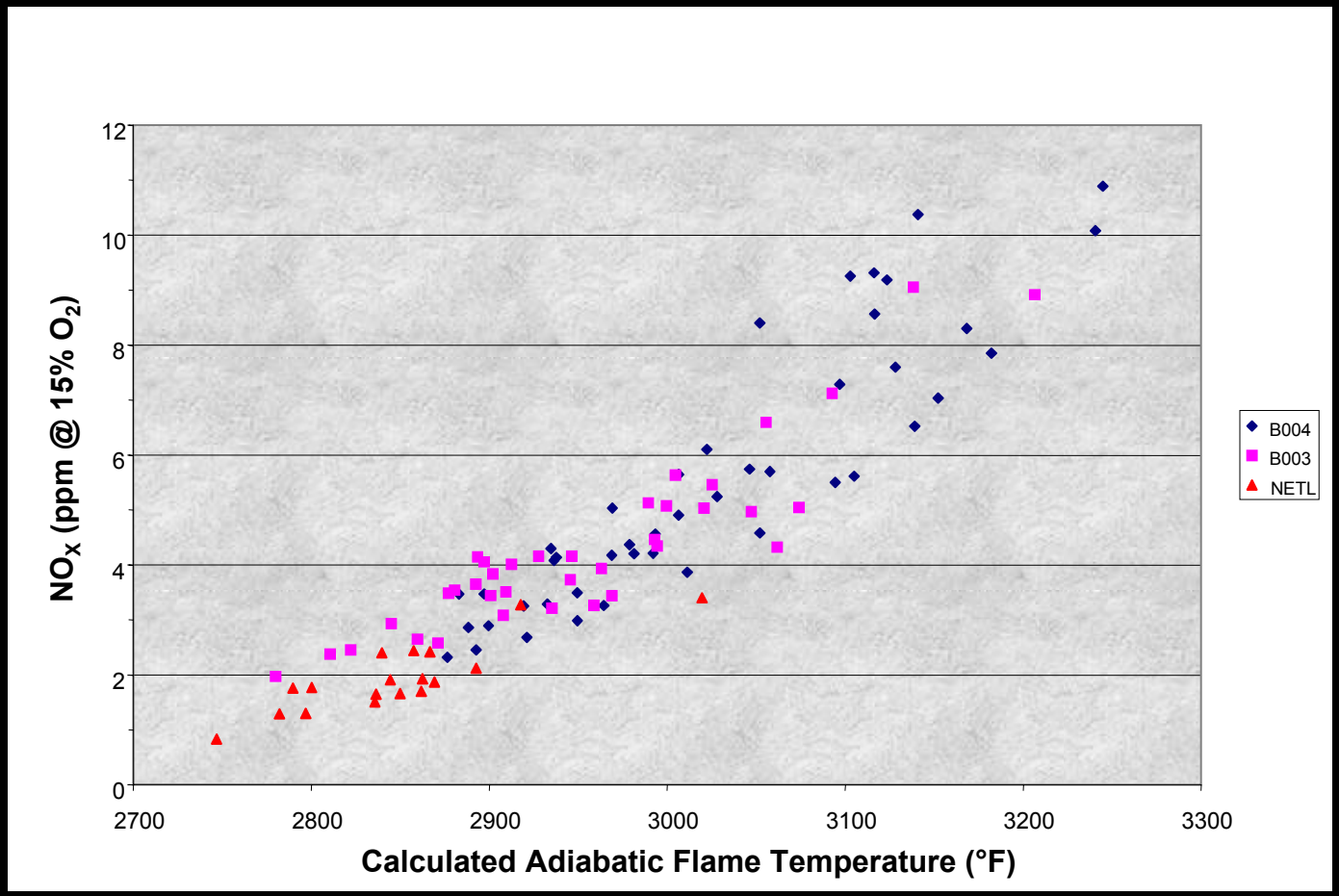
Emissions Data



ALZETA CORPORATION

Advanced Combustion Clean Air Solutions for Industry and Our Environment

Comprehensive Emissions Data



ALZETA CORPORATION

Advanced Combustion Clean Air Solutions for Industry and Our Environment

Summary

- Saturn Demonstration proved reliable ignition, stable operation, compatibility with existing controls and ability to provide motive power for a gas turbine engine.
- Materials development resulted in monolithic metal fiber injectors free of weld seams.
- Atmospheric testing established uniform flow and flame distribution over injector surface.
- Engine ready mixer development proceeding.
- Pressurized tests at simulated Taurus 60 operating conditions demonstrated stable operation at every condition.

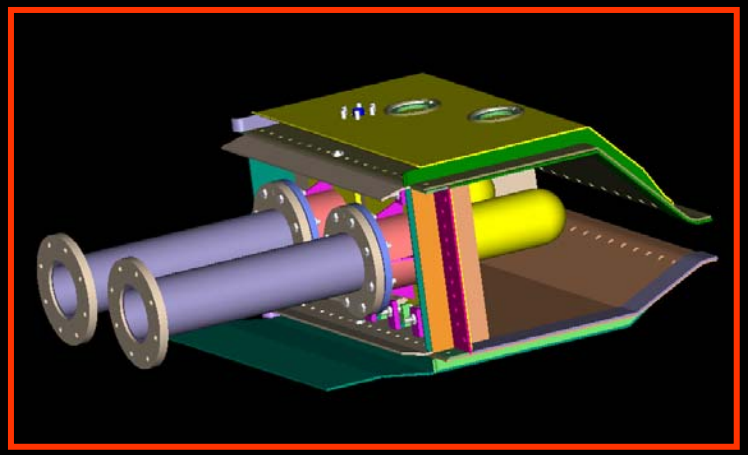
Summary

- Low NO_X (2 ppm @ 15% O_2) performance was demonstrated at full-load pressure.
- Performance mapping (lean blowout) testing at several pressures showed sub 3 ppm NO_X emissions, but lowest AFT before instability was not as good as previous results at NETL.
- A broad range of Surface Firing Rates (0.6 – 1.7 MMBtu/hr-ft^2-atm) were demonstrated at pressures up to 12 atmospheres.

Remaining Tasks

- Partial Annular test of multiple injectors
- Adjust porous material properties to improve lean stability
- Dual zone injector pressurized test
- Full Annular test in loop rig
  - Controls Specification
  - Fabricate full set of injectors
  - Mate injectors with new compact mixers
  - Demonstrate ultra-low emissions

Partial Annular Tests - Sector Rig



- Test for proximity effects of 2-3 burners
- Utilize existing pressure vessel
- Backside-cooled liner simulates engine annulus
- Distance between burners adjustable
- Two quartz windows for visual access

ALZETA CORPORATION